

Title: Nonlinear Dynamics of Global Atmospheric and Earth-System Processes

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Significant Accomplishments in the Past Year:

- 1) Theoretical Studies of Planetary Waves and Low Frequency Atmospheric Variability. During the past year we completed two papers dealing with the dynamical properties of the planetary waves in the atmosphere; both of these studies point to possible sources of the observed systematic errors in numerical weather predictions. In the first of these papers, Ebisuzaki (1990) shows that eastward-tilting, westward-moving waves are a distinctive feature of the mid-latitudes, particularly in winter. One source of these waves is the interaction of baroclinic unstable waves with standing waves forced by the continents and ocean; a failure to model these interactions correctly can be a significant source of long wave error in numerical predictions.

In the second paper, Pandolfo and Sutera (1990) discuss the effects of the zonal mean wind variability on the energy propagation of a stationary Rossby wave in a barotropic non-divergent atmosphere are studied. It is shown that the random nature of the zonal wind fluctuations do not allow Rossby wave energy to propagate from its energy source. The mechanisms for this effect is strongly dependent on the spatial resolution at which the zonal mean flow is assumed to be known; this suggests that models with too low a latitudinal resolution will allow too much wave energy to propagate from middle latitudes resulting in systematic errors similar to those observed.

- 2) GCM Studies of the Atmospheric Response to Boundary Conditions Observable by Satellites. A series of GCM sensitivity experiments have been conducted to determine the atmospheric response to significant features of the earth's surface that are measured by systematic satellite observations; these are (i) surface soil moisture (Oglesby and Erickson 1989), (ii) localized sea-surface temperature, over the Gulf of Mexico (Maasch and Oglesby 1990), and (iii) sea ice coverage (Oglesby 1990). In addition, an important sensitivity study for the response of surface air temperature to systematic changes in atmospheric carbon dioxide ranging from 100 to 1000 ppm was completed (Oglesby and Saltzman 1990); the response is found to be nonlinear,

showing greater sensitivity for lower values of CO<sub>2</sub> than for the higher values. It is suggested that changes in CO<sub>2</sub> concentration of a given magnitude (e.g., 100 ppm) play a larger role in the Pleistocene ice age type temperature variations, than in causing global temperature changes due to anthropogenic increases.

- 3) Dynamical studies of Long-Term Variations of the Global Earth-System. In a series of papers (Maasch and Saltzman 1990, Saltzman and Maasch 1990a,b) we have explored the degree to which the major changes in terrestrial climate and the carbon dioxide concentration associated with the Pleistocene "ice ages" can be accounted for internally by complex nonlinear interactions involving the atmosphere, biosphere, hydrosphere, and cryosphere. In the last of these contributions we show how positive feedbacks in the global carbon cycle, as controlled by the deep ocean state, can provide the instability to drive the major ice age cycle. When additive external forcing (e.g., due to earth-orbital, Milankovitch, radiative variations) is applied, much of the inferred global variations of climate over the past 2 million years, including the "jump" about 900 thousand years ago, can be explained with a relatively small number of adjustable parameters. The consequences of this model for the effects of the anthropogenic CO<sub>2</sub> increase have also been explored (Saltzman and Maasch 1990c), showing that this increase may have displaced the slow-response earth-system to a dynamical domain far from that of the ice-age oscillations prevailing over the last million years.

#### Focus of Current Research and Plans for Next Year:

We are continuing our studies of the nonlinear dynamics of global weather systems, emphasizing the following specific tasks:

- 1) Sensitivity analyses of large-scale dynamical models of the atmosphere (i.e., general circulation models i.e., GCM's) to establish the role of satellite-signatures of soil moisture, sea surface temperature, snow cover, and sea ice as crucial boundary conditions determining global weather variability.
- 2) To complete our study of the bimodality of the planetary wave states, using the dynamical systems approach to construct a low-order theoretical explanation of this phenomenon. This work should have important implications for extended range forecasting of low-frequency oscillations, elucidating the mechanisms for the transitions between the two wave modes.
- 3) To use the methods of "jump" analysis and "attractor dimension" analysis studied under the previous grant, to examine the long-term satellite records of significant variables (e.g. long wave radiation, and cloud amount), to explore the nature of mode transitions in the atmosphere, and to determine the minimum number of equations needed to

describe the main weather variations with a low-order dynamical system.

- 4) Where feasible we will continue to explore the applicability of the methods of complex dynamical systems analysis to the study of the global earth-system from an integrative viewpoint involving the roles of geochemical cycling and the interactive behavior of the atmosphere, hydrosphere, and biosphere.

#### Publications (1989-1990)

- 1) Maasch, K. A. and B. Saltzman, 1990: A low-order dynamical model of global climatic variability over the full Pleistocene. J. Geophys. Res., 95, 1955-1963.
- 2) Oglesby, R. J. and E. J. Erickson III, 1989: Soil moisture and the persistence of North American drought. J. Climate, 2, 1362-1380.
- 3) Oglesby, R. J. and B. Saltzman, 1990: Sensitivity of the equilibrium surface temperature of a GCM to systematic changes in atmospheric carbon dioxide. Geophys. Res. Lett., (in press).
- 4) Saltzman, B. and K. A. Maasch, 1990a: A first-order global model of late Cenozoic climatic change. Trans. Roy. Soc. Edinburgh, (in press).

#### Submitted for Publication

- 1) Ebisuzaki, W., 1990: Vertical tilts of tropospheric waves: observation and theory. J. Atmos. Sci. (submitted).
- 2) Maasch, K. A. and R. J. Oglesby, 1990: Meltwater cooling of the Gulf of Mexico: GCM implications for climatic conditions at 12 ka. Paleoceanography (submitted).
- 3) Oglesby, R. J., 1990: The influence of sea ice extent on the Southern Hemisphere oceanic and atmospheric circulation. (abstract, manuscript in preparation).
- 4) Pandolfo, L. and A. Sutera, 1990: Rossby waves in a fluctuating zonal mean flow. Tellus (submitted).
- 5) Saltzman, B. and K. A. Maasch, 1990b: A first-order global model of late Cenozoic climatic change II. A simplification of CO<sub>2</sub> dynamics. Climate Dynamics (submitted).
- 6) Saltzman, B. And K. A. Maasch, 1990c: Possible effects of increased CO<sub>2</sub> on the structural dynamics of climate: implications for ice age cycles. Science (submitted).

